

# Long-term trends and the role of eutrophication in Puget Sound

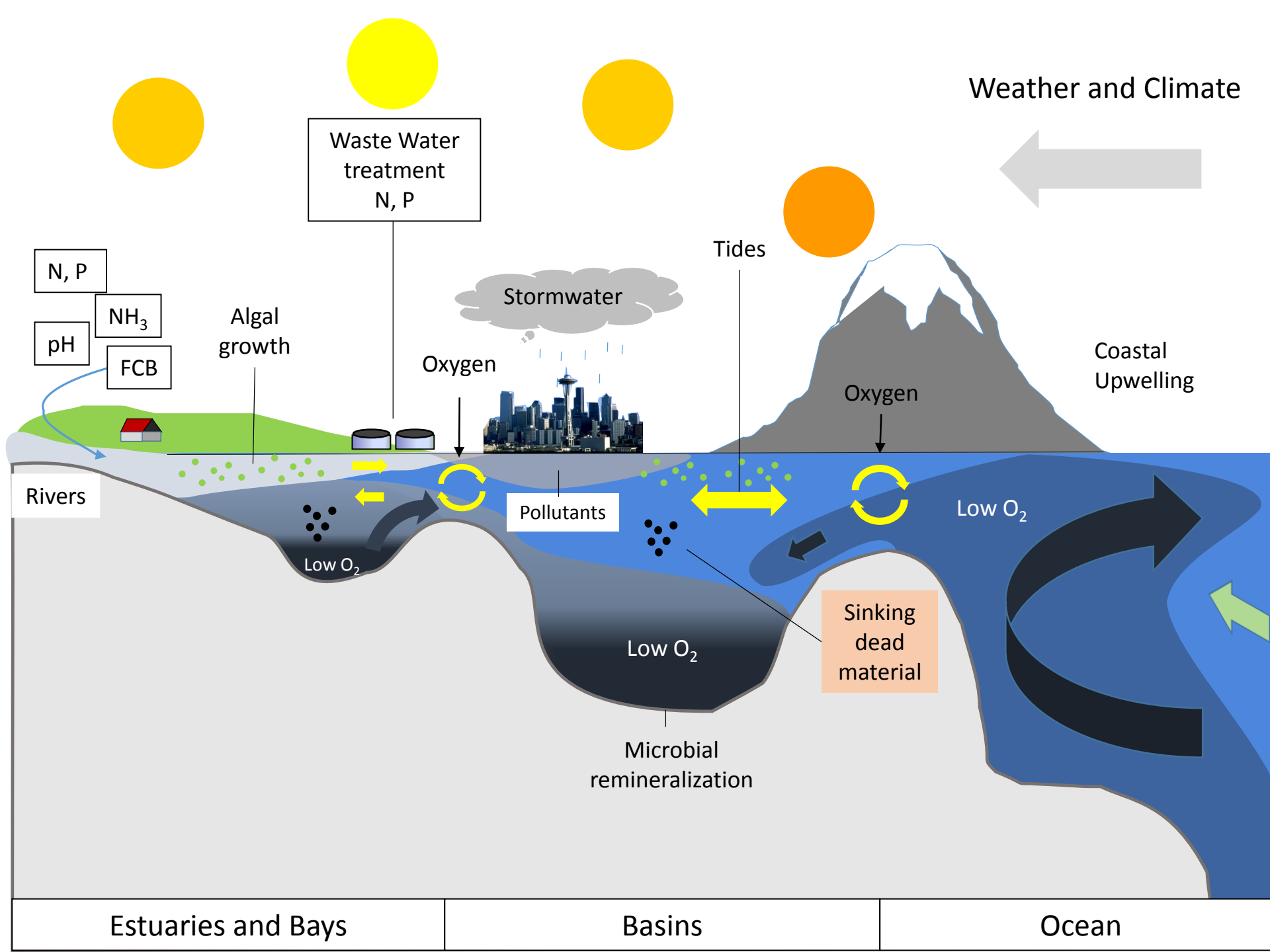
*Dr. Christopher Krembs, Marine Monitoring Unit, Ecology*

*EPA Region 10, 3/29/2016*



Are we  
losing the  
benefits  
of the  
sediment?

<http://www.underwatersculpture.com/>



**Puget Sound is  
a deep fjord  
(avg 60m)**

**Changes in sinking  
particles matters more  
than in other places!**



# Eyes Over Puget Sound, monthly condition report

[Field log](#)[Weather](#)[Water column](#)[Aerial photos](#)[Ferry and Satellite](#)[Moorings](#)

Flagellates thrive in water:

- rich in organic molecules
- stratified

*Red-brown bloom mixed into sediment-rich river plume. Jellyfish patches.*

Location: Deepwater Point, Totten Inlet (South Sound), 10:27 AM.



Hypothesis

EOPS

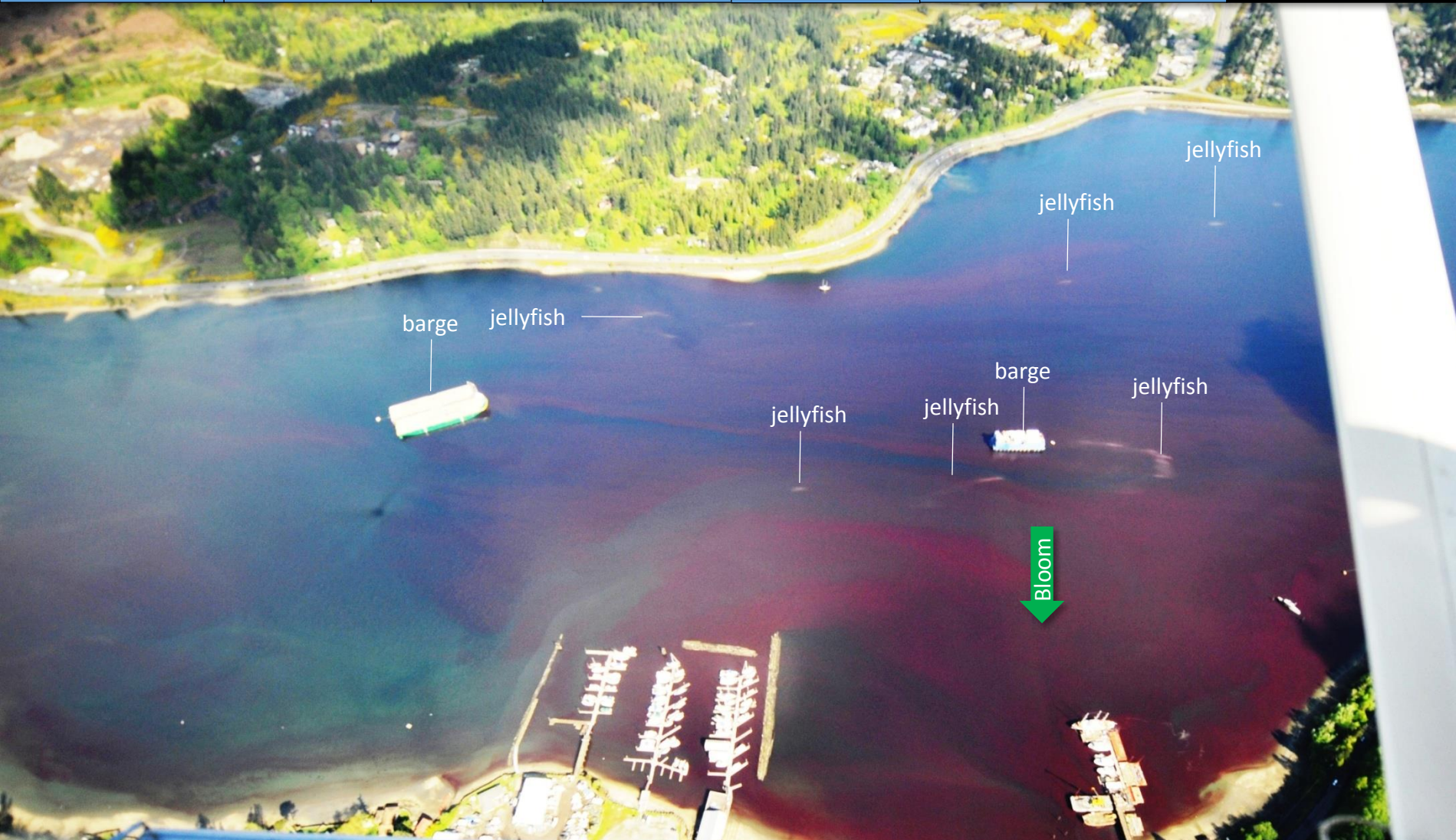
People

Climate

Beach

Water column

Aerial photos



Flagellates thrive in water:

- rich in organic molecules
- stratified
- flagellates are auto, mixo or heterotrophic
- opportunistic

*Red bloom and patches of jellyfish.*

Location: Kitsap Marina, Sinclair Inlet (Bremerton), 9:52 AM.



# Eyes Over Puget Sound

[Flight log](#)[Weather](#)[Water column](#)[Aerial photos](#)[Ferry and Satellite](#)[Moorings](#)

June 2013

sail boat

Noctiluca has an impact on:

- food web structure
- biogeo-chemical processes
- considered a eutrophication indicator





Field log

Climate

Water column

Aerial photos

Ferry monitoring

Streams



Noctiluca has an impact on:

- food web structure
- biogeochemical processes
- considered a eutrophication indicator

*Large Noctiluca bloom surfacing and gathering in large quantities at tidal front.*

Location: Commencement Bay (Central Sound), 3:32 PM.





Field log

Climate

Water column

Aerial photos

Continuous monitoring

Streams



Macro-algae:

- Eutrophication indicator

*Extensive accumulations of organic debris, a brown algal bloom, and a large oil sheen.*  
Location: Between Port Madison and Shilshole (Central Sound), 3:05 PM.



Field log

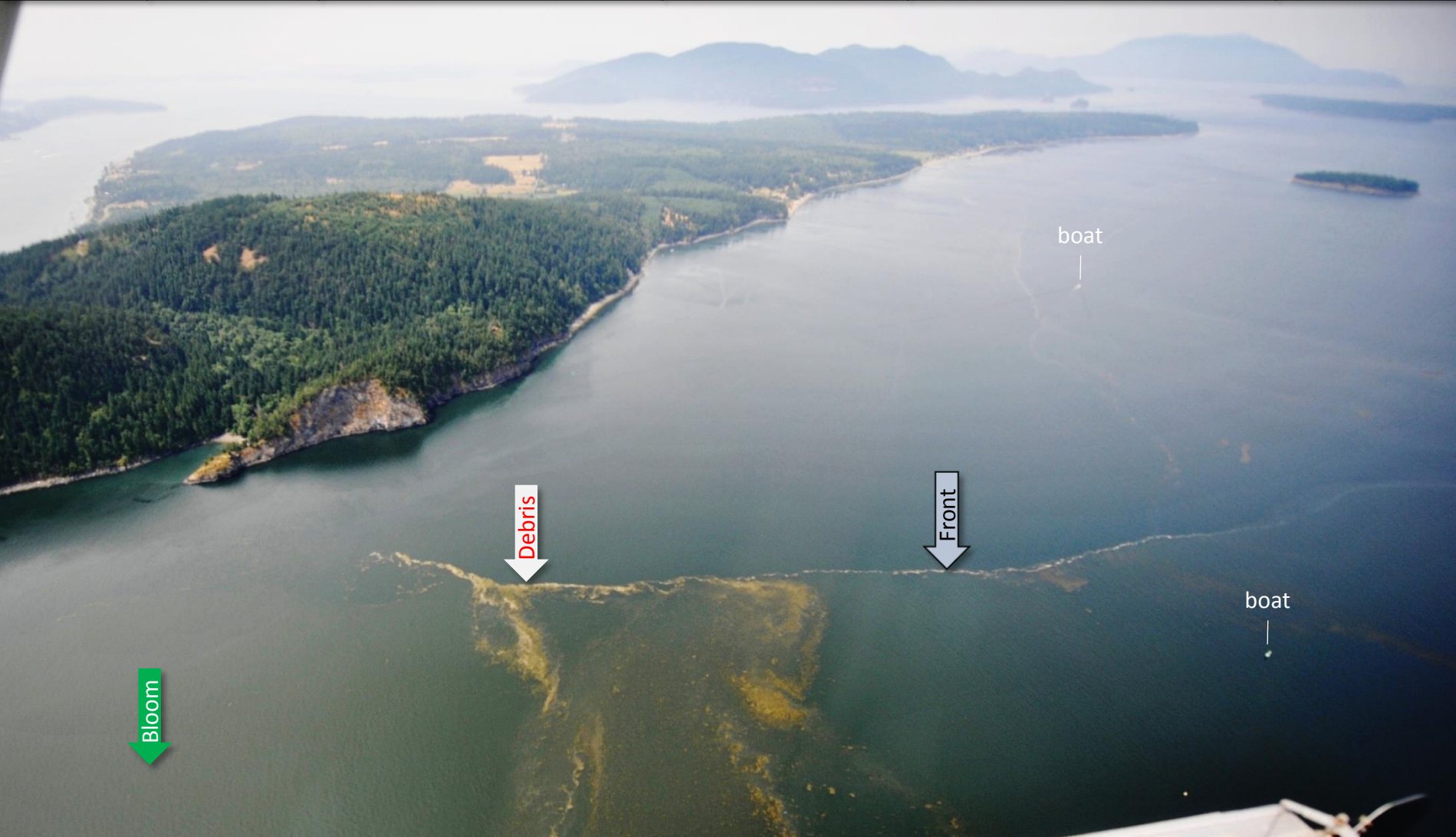
Climate

Water column

Aerial photos

Continuous monitoring

Streams



## Macro-algae:

- Eutrophication indicator
- occur in summer
- poor food for plankton species

*Large islands of organic material drifting at the surface off Guemes Island.*

Location: Padilla Bay (North Sound), 1:05 PM.



# Eyes Over Puget Sound

[Field log](#)[Climate](#)[Water column](#)[Aerial photos](#)[Ferry and Satellite](#)[Moorings](#)

## Surface Conditions Report

October 29, 2014

Guest: Gabriela Hannach

[Start here](#)

*Up-to-date observations of visible water quality conditions in Puget Sound and the Strait of Juan de Fuca*





Field log

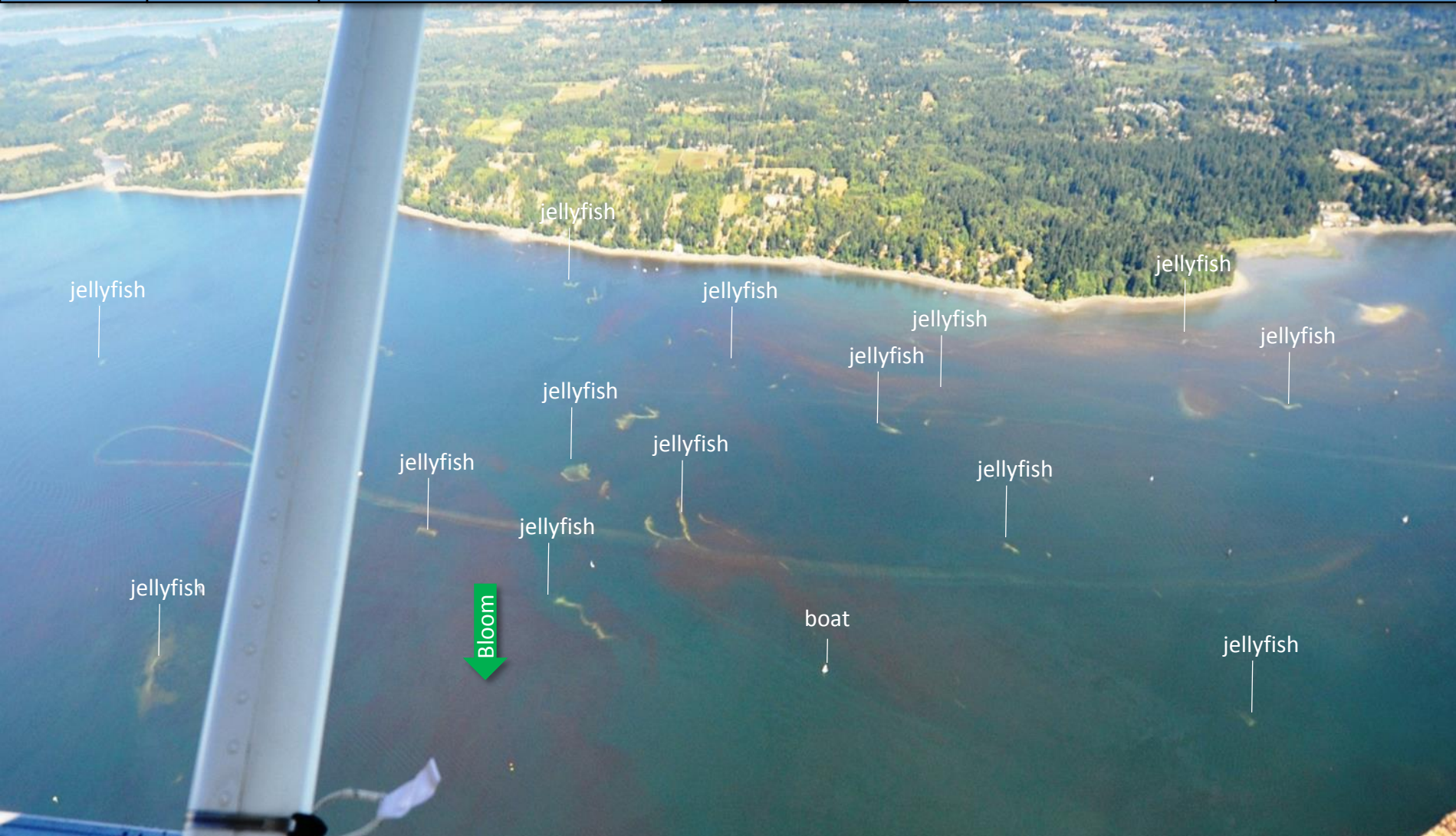
Climate

Water column

Aerial photos

Continuous monitoring

Streams



## Jellyfish:

- Eutrophication indicator

*Numerous large patches of jellyfish in water containing red-brown algal bloom.*

Location: Budd Inlet (South Sound), 3:12 PM.





Field log

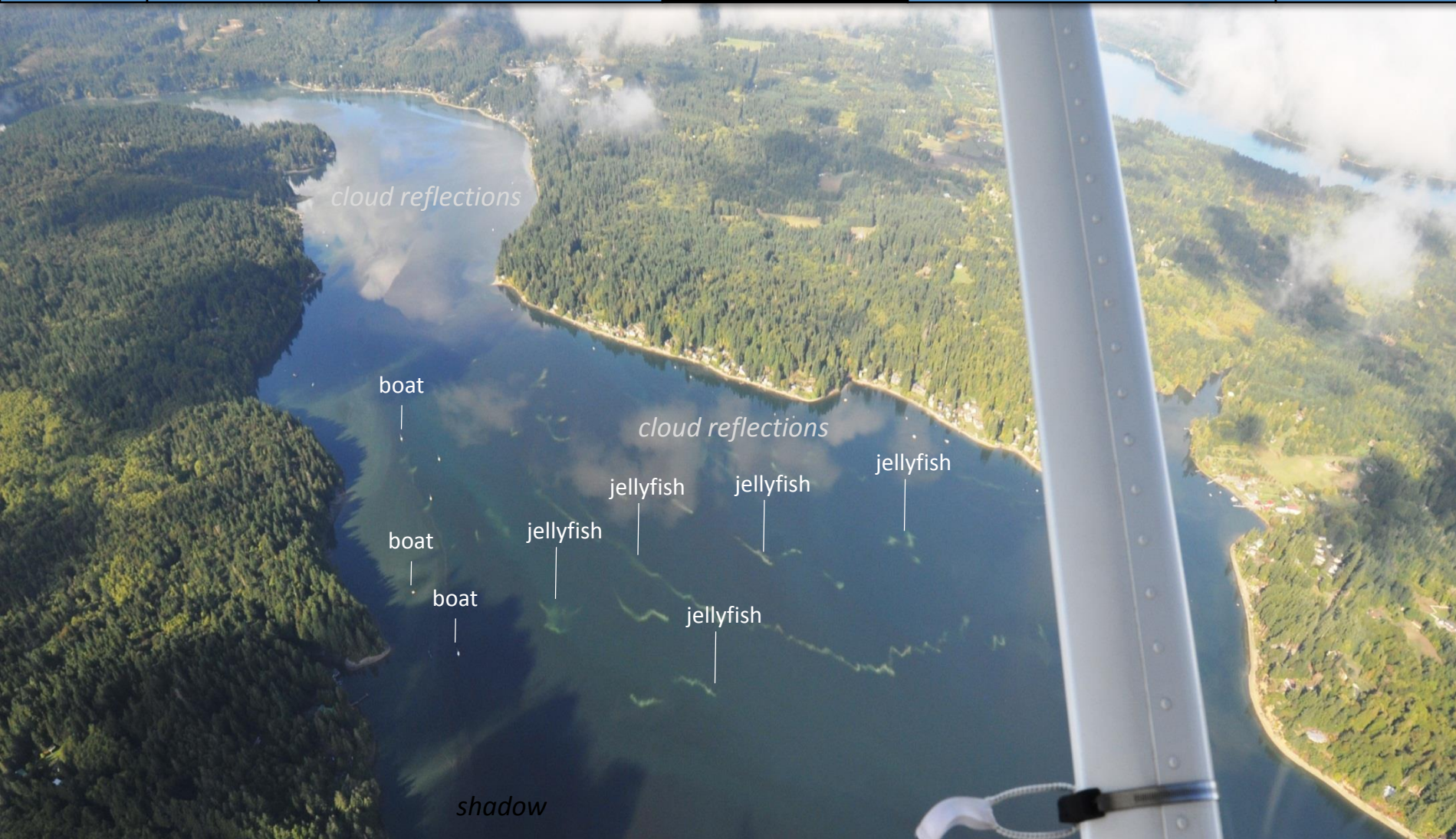
Climate

Water column

Aerial photos

Continuous monitoring

Streams



## Jellyfish:

- Eutrophication indicator
- occur abundantly in summer-fall
- poor food

*Large jellyfish patches in water containing fading red-brown algal bloom.*

Location: Eld Inlet (South Sound), 10:24 AM.





Field log

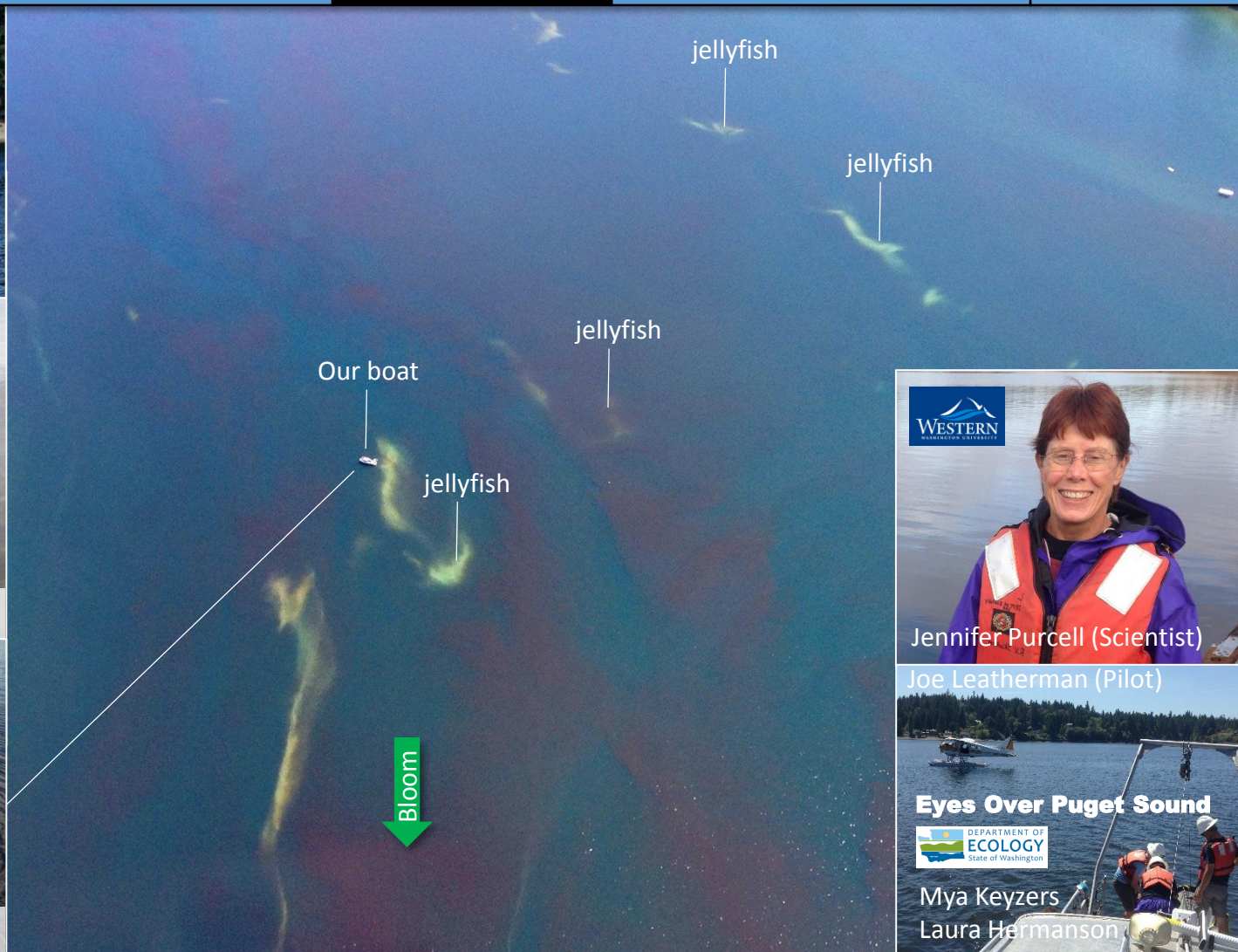
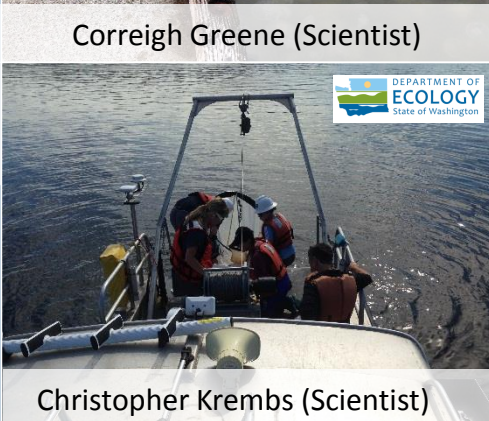
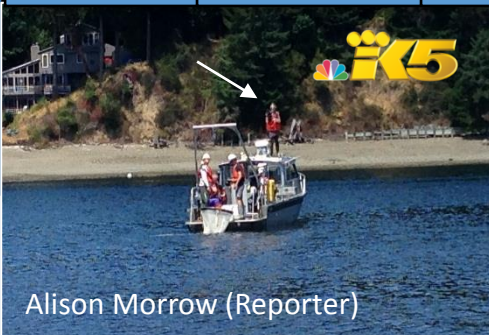
Climate

Water column

Aerial photos

Continuous monitoring

Streams



## Jellyfish:

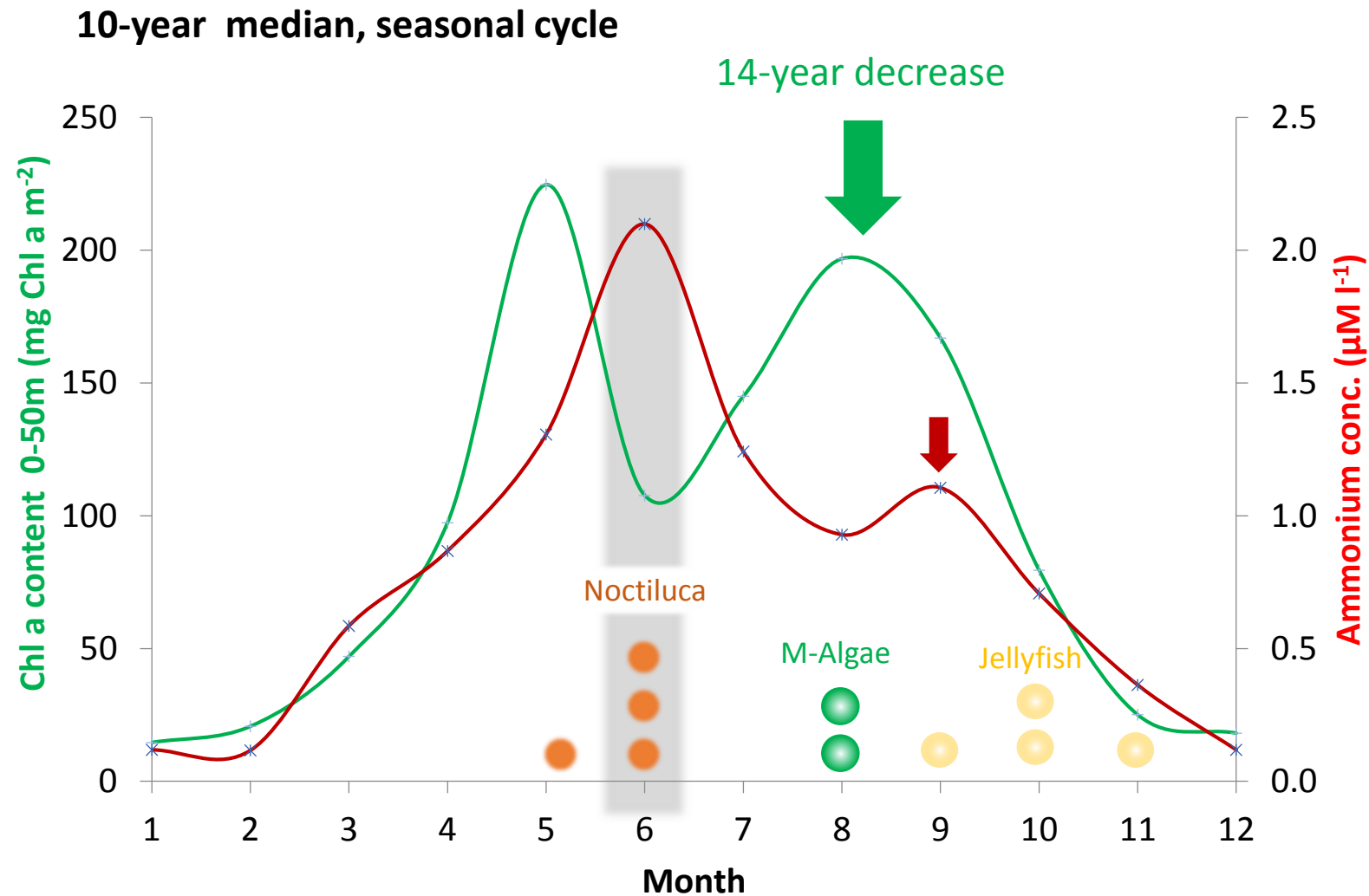
- Eutrophication indicator
- occur abundantly in summer fall
- poor food

*Collaborating on air to ground measurements of jellyfish super smacks (this one is > 2 million individuals)*

Location: Eld Inlet (South Sound, 1400 ft), 1:10 PM.



# Grazing is reflected in the seasonality of phytoplankton biomass (and $\text{NH}_4$ ) in Puget Sound (15 year median)

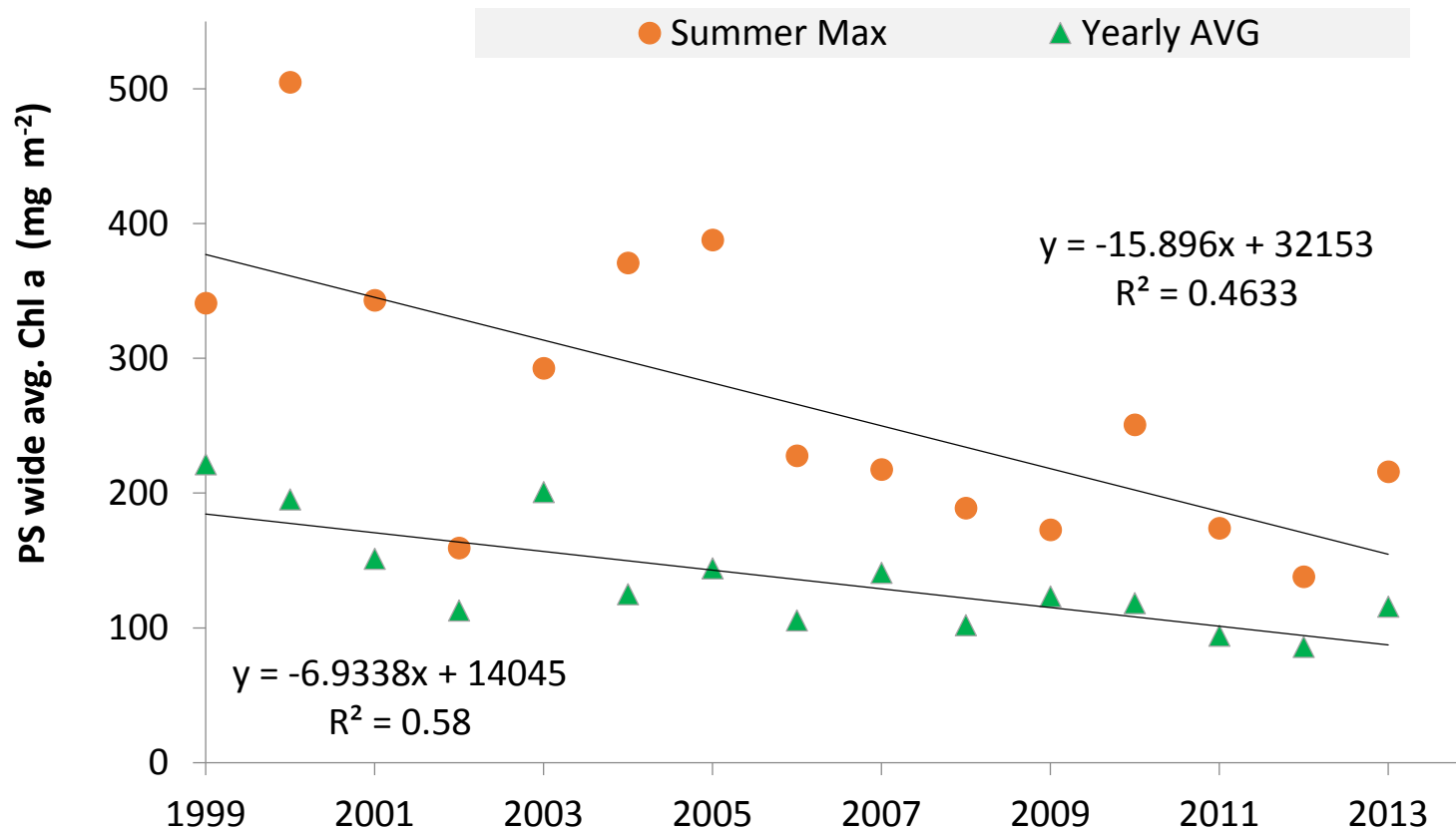


Phytoplankton dynamics  
change in summer

The spring bloom  
characteristics remain  
similar over the last  
15 years

# Chl a summer peak loses its strength

**Note:**  $\text{NH}_4$  max also decreases in late summer; average is unchanged



Phytoplankton dynamics  
change in summer

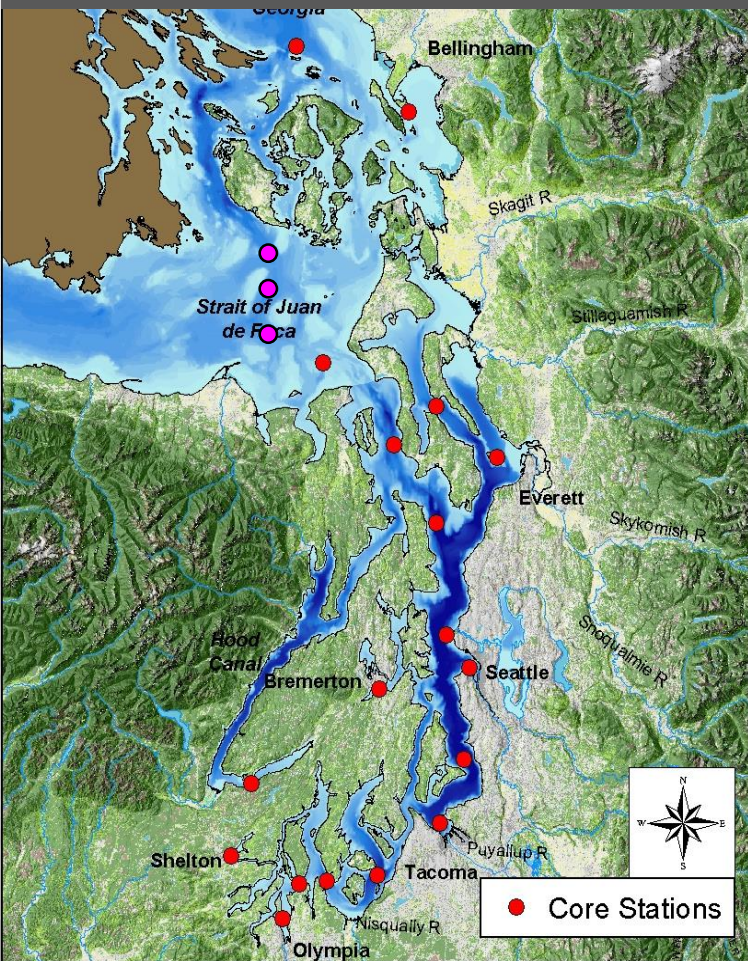
The spring bloom  
characteristics remain  
similar

A response to changing nutrient supply of glacier-fed rivers?

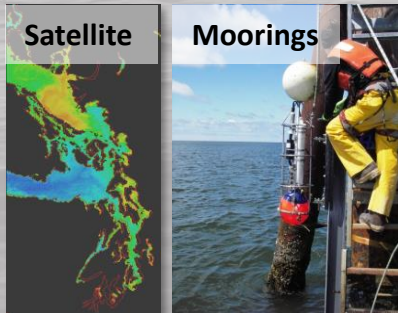


# Measuring long-term trends in eutrophication, dissolved oxygen and physical variables

## Greater Puget Sound region



## Water Quality variables measured monthly at 27 stations



### Physical variables

- Temperature
- Salinity
- Density

### Chemical variables

- Oxygen
- Nitrate
- Silicate
- Phosphate
- Ammonium
- Nutrient ratios
- pH

### Bio-optical variables

- Water clarity
- Chlorophyll a
- Euphotic depth

Monthly  
Baselines  
1999-2008

## “The Holy Grail”

How much are humans influencing water quality

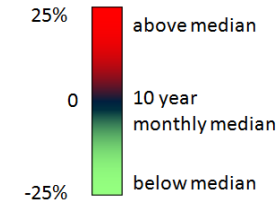
If natural influences are known, human influences can be scaled



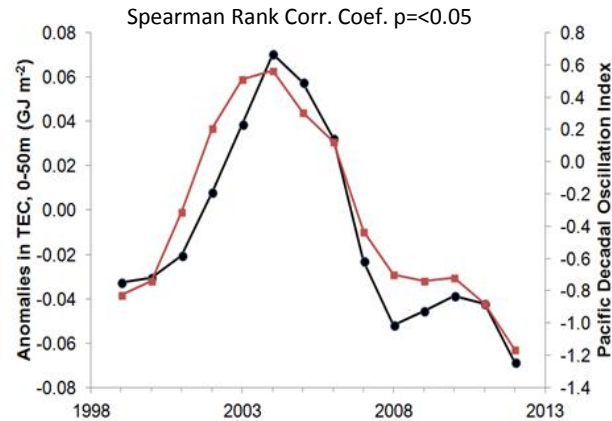
# Ocean boundary conditions impact PS water quality

**A-B** Sea Surface Temperature - Pacific Decadal Oscillations Index

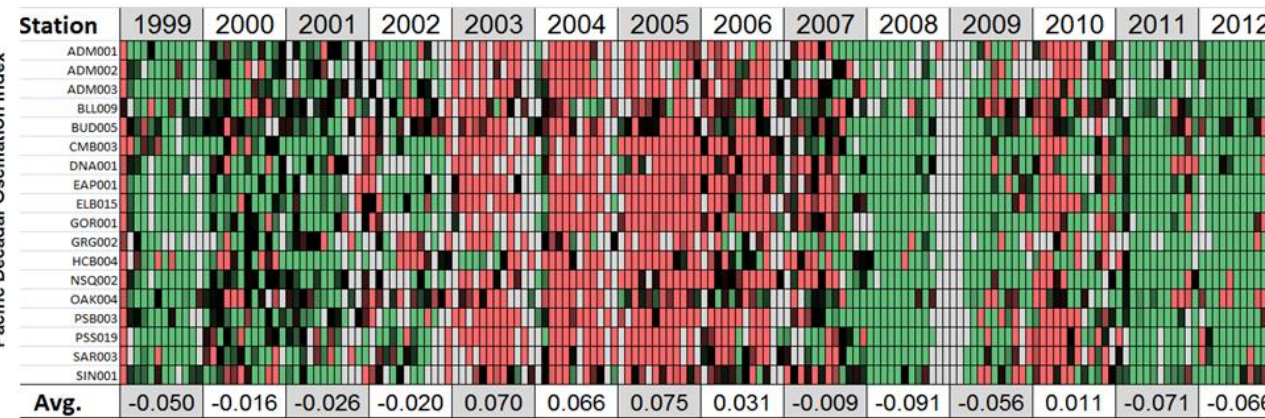
**C-D** Upwelling - Upwelling Index (anomalies)



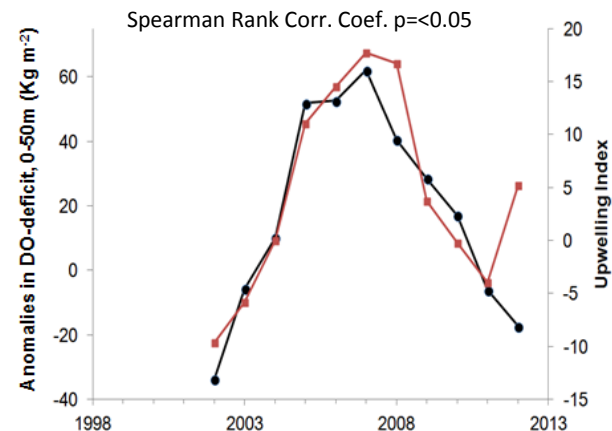
**A.** Pacific Decadal Oscillation Index



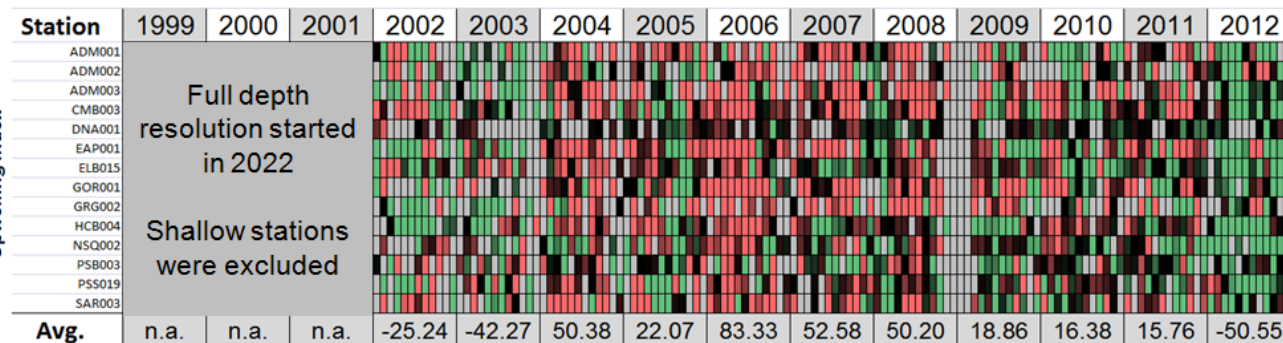
**B.** Anomalies in Thermal Energy Content, 0-50m



**C.** Upwelling Index (NOAA)



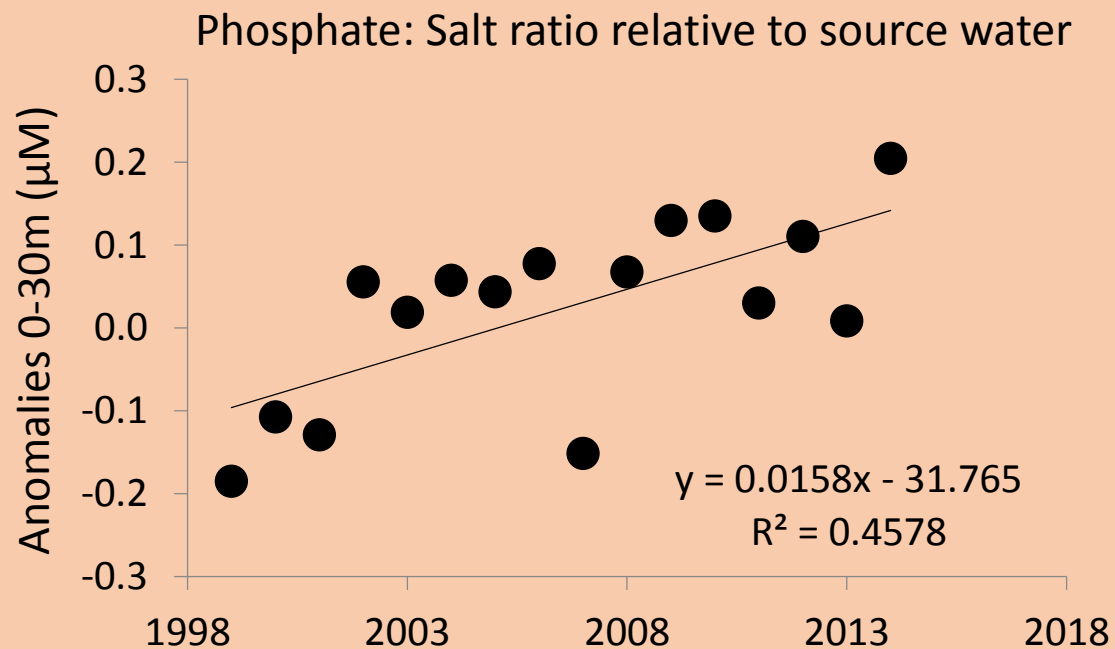
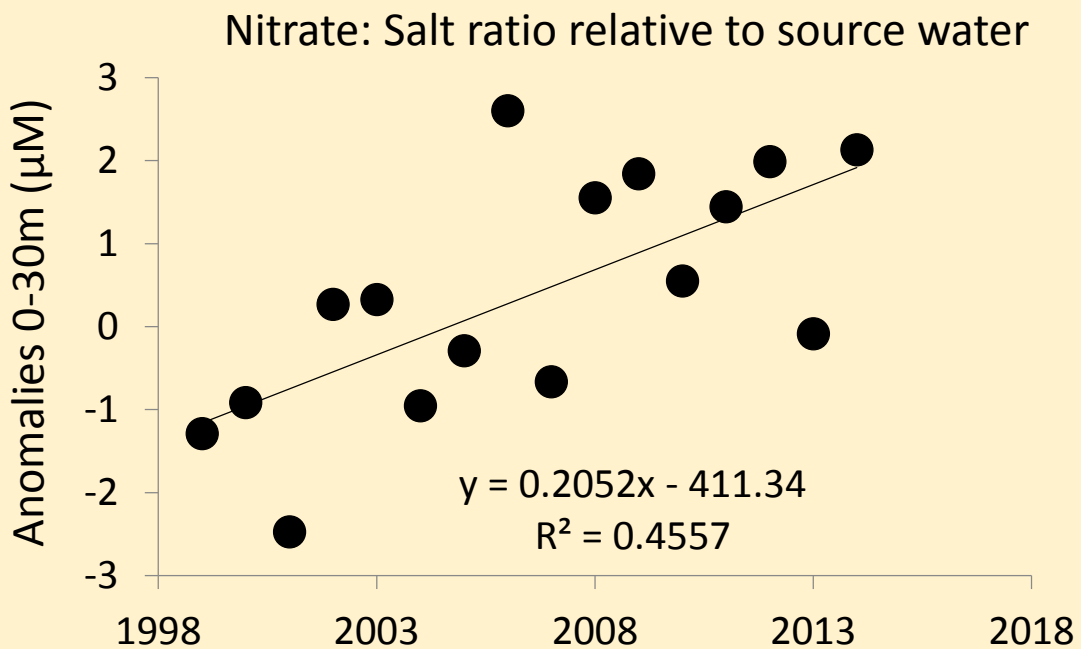
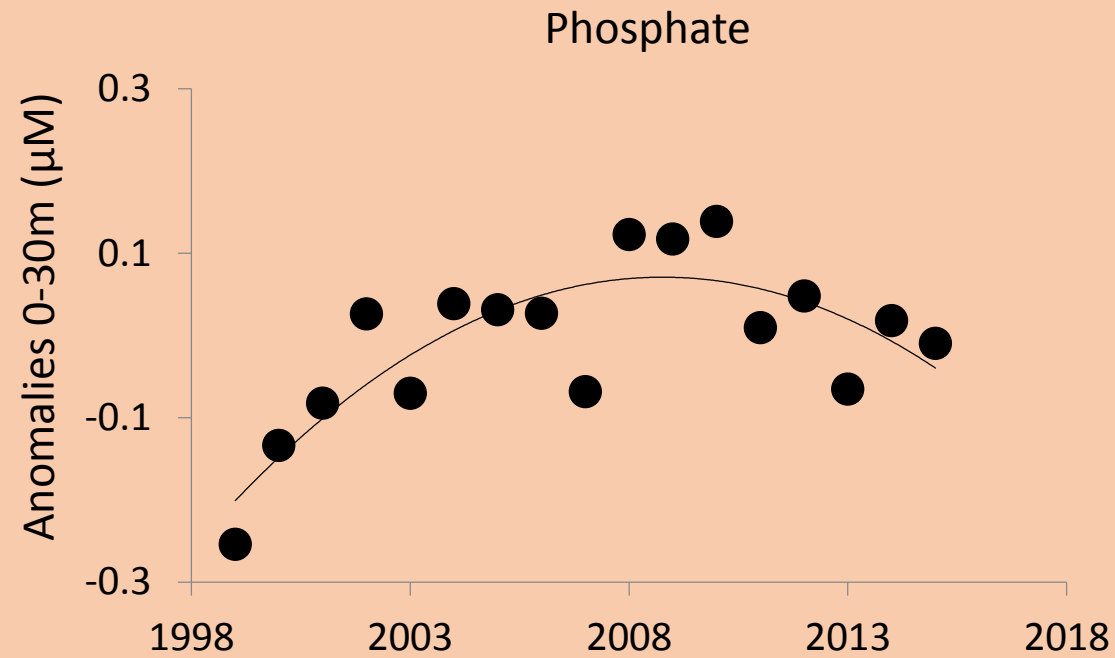
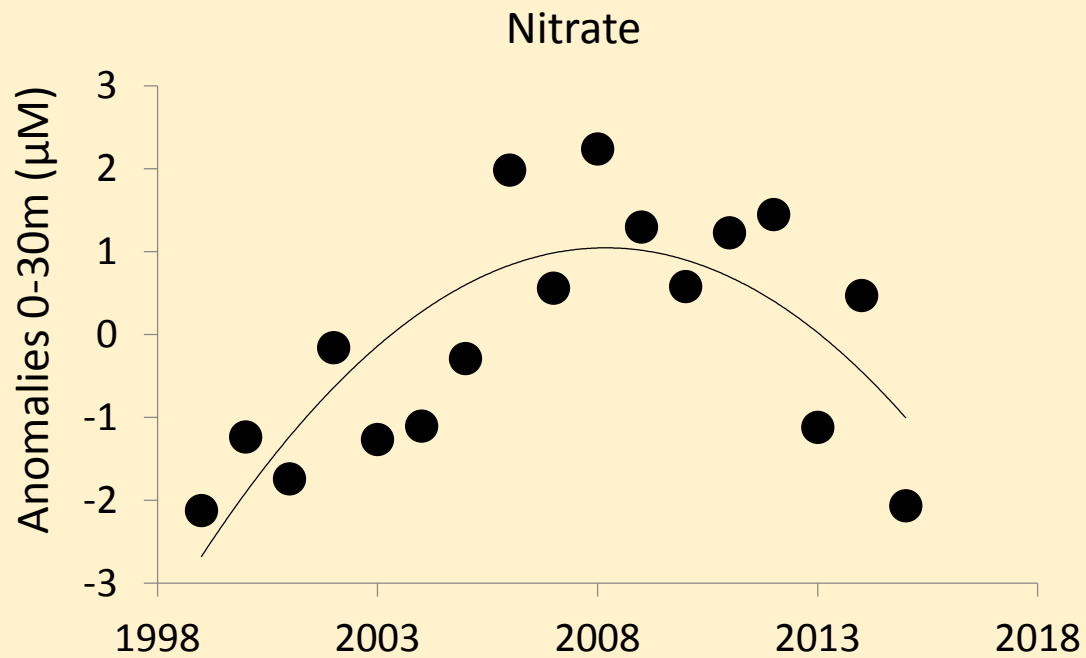
**D.** Anomalies in Dissolved Oxygen Deficit, >50 m



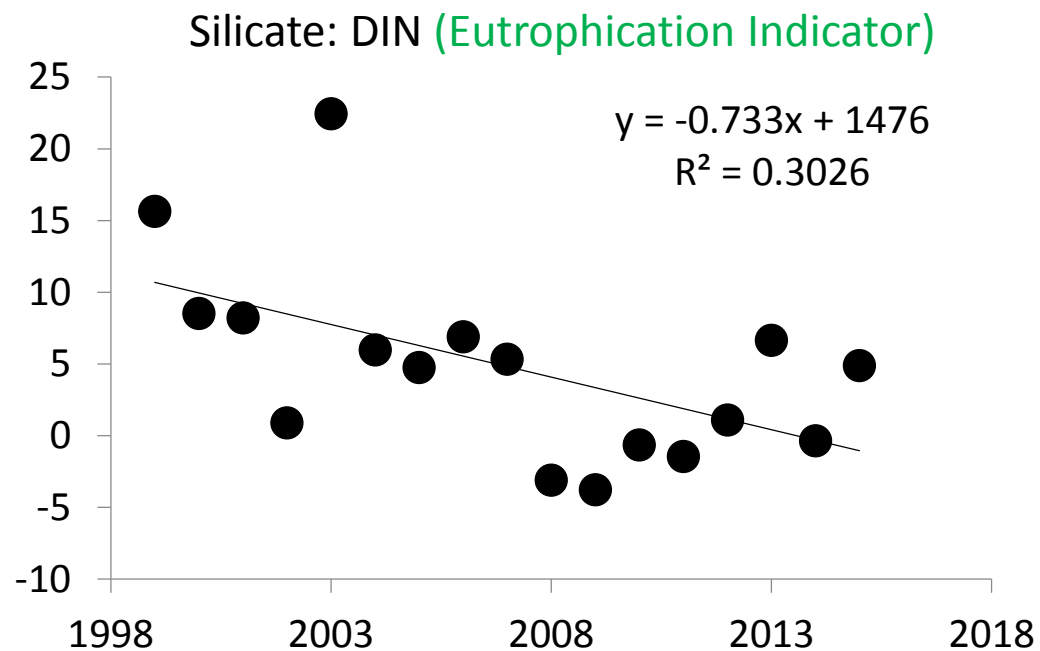
**PS responds to ocean conditions at the surface**

**Physical variables at depth respond also to coastal variations**





# Nutrient balance is changing at the base of the food web



Si:DIN variations in ocean source water is 1-2 orders of magnitude lower (ocean not a driver)



# Dilemma: Nutrients in PS are increasing?

- Nitrogen loading from rivers are relatively unchanged.

- Hallock, D., 2008. River and Stream Water Quality Monitoring Report, Water Year 2008.

Washington State Department of Ecology, Olympia, WA.

- Von Prause, M., 2014. River and Stream Water Quality Monitoring Report, Water Year 2013.

Washington State Department of Ecology, Olympia, WA.

- Nitrogen loading from sewage treatment plants, unchanged.

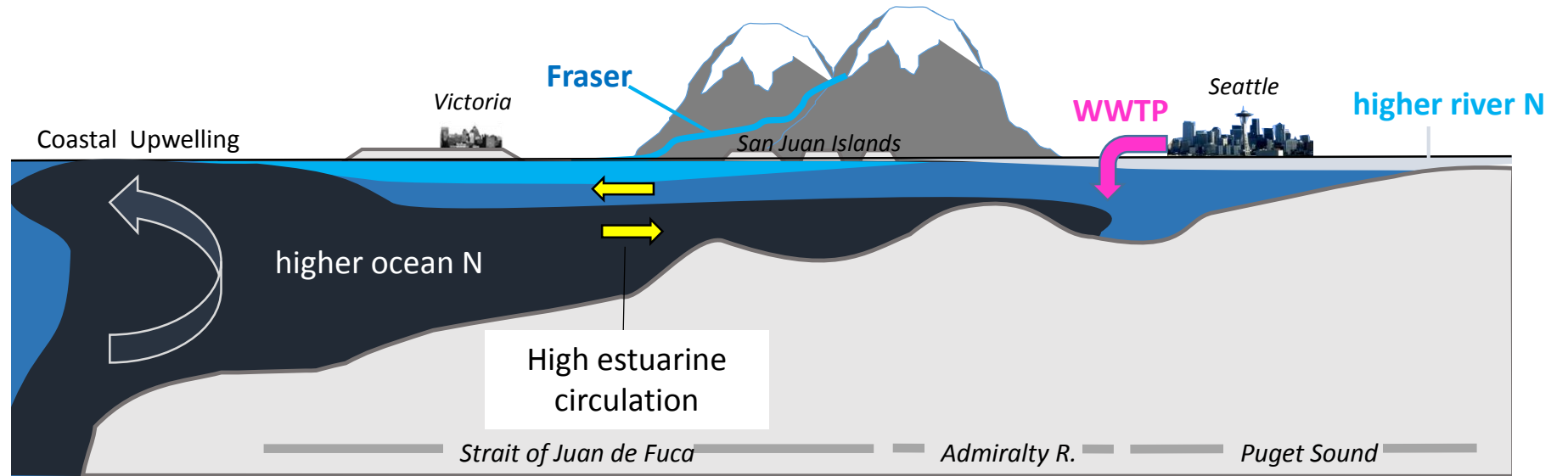
- Mohamedali, T., M. Roberts, B. Sackmann, and A. Kolosseus. 2011. Puget Sound Dissolved Oxygen Model Nutrient Load Summary for 1999-2008.

Washington State Department of Ecology, Olympia, Washington.

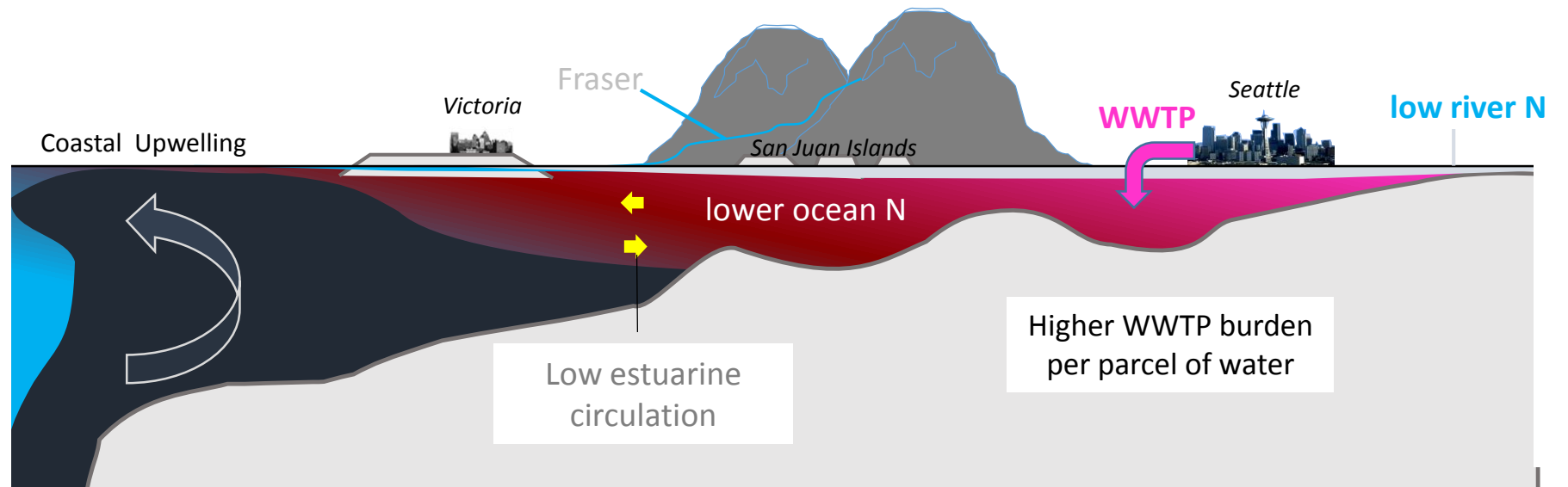
- Nitrogen trends not visible in ocean source water to Puget Sound

Status and trends of organically-bound nutrients are missing!

normal snowpack



reduced snowpack

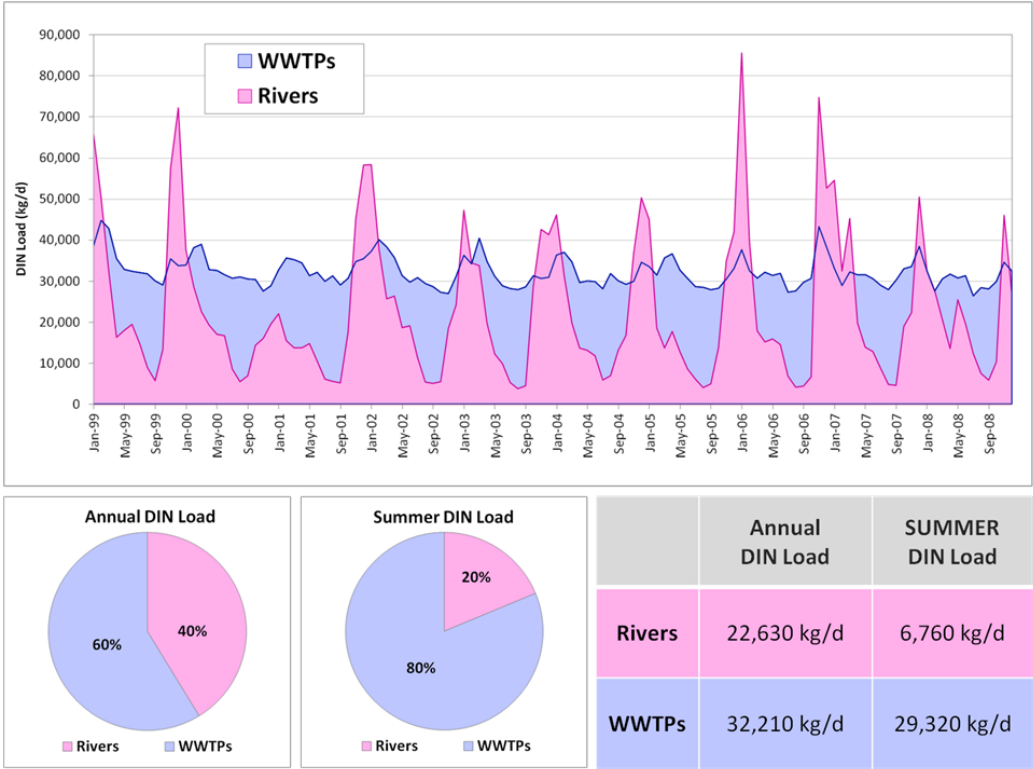


River flows drive  
“natural” nutrient  
inputs directly and  
indirectly.

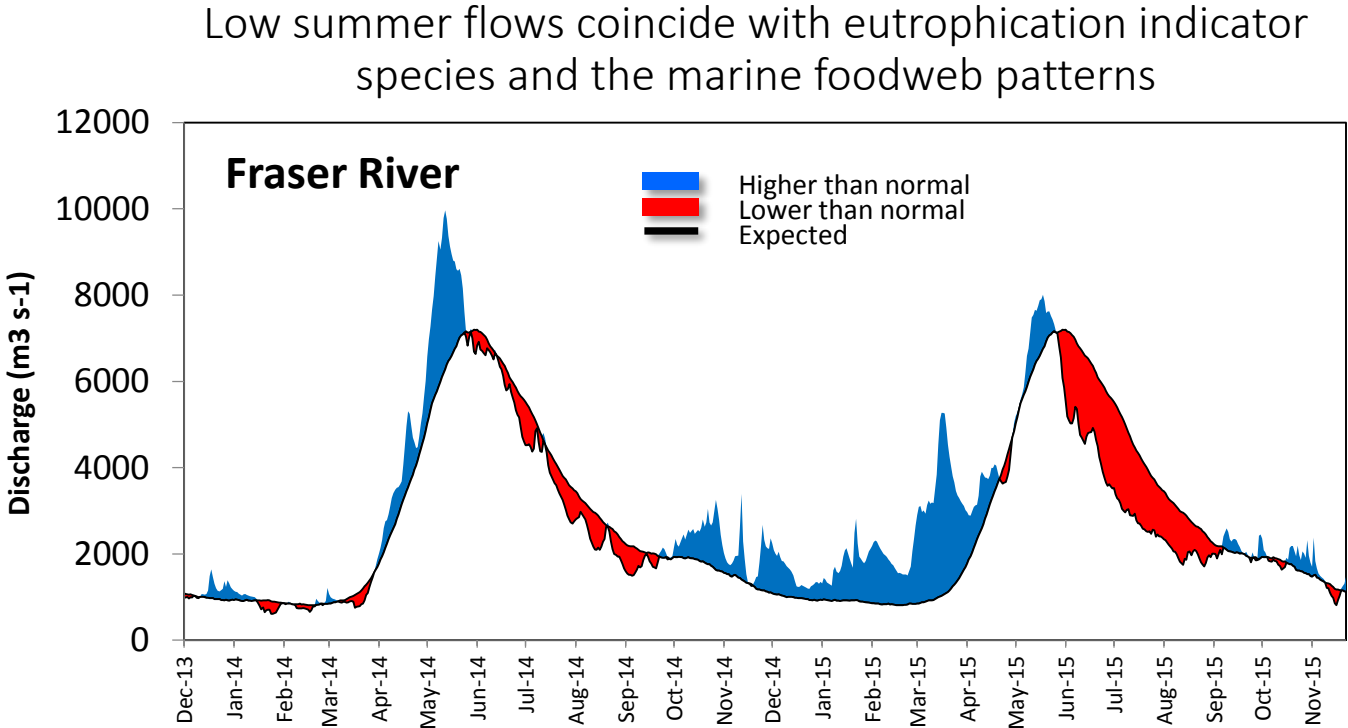
Low river flows  
promote  
qualitative  
nutrient  
differences.



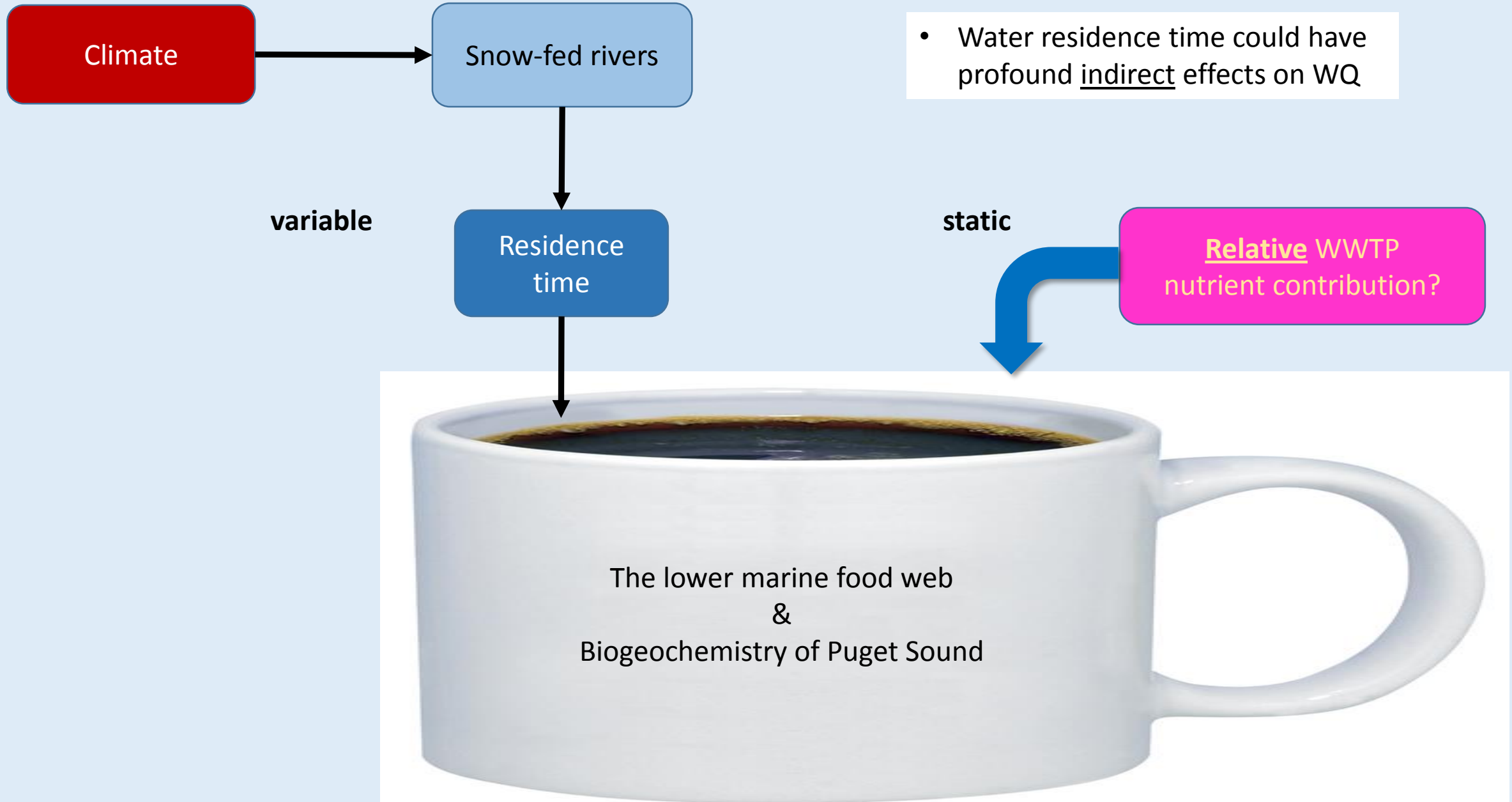
In summer the relative contributions of WWTP is highest, higher water residence time might promote nuisance species



Comparison of dissolved inorganic nitrogen (DIN) load from rivers (pink) and wastewater treatment plants (blue) into Puget Sound (Source: [Mohamedali et al., 2011a](#)).

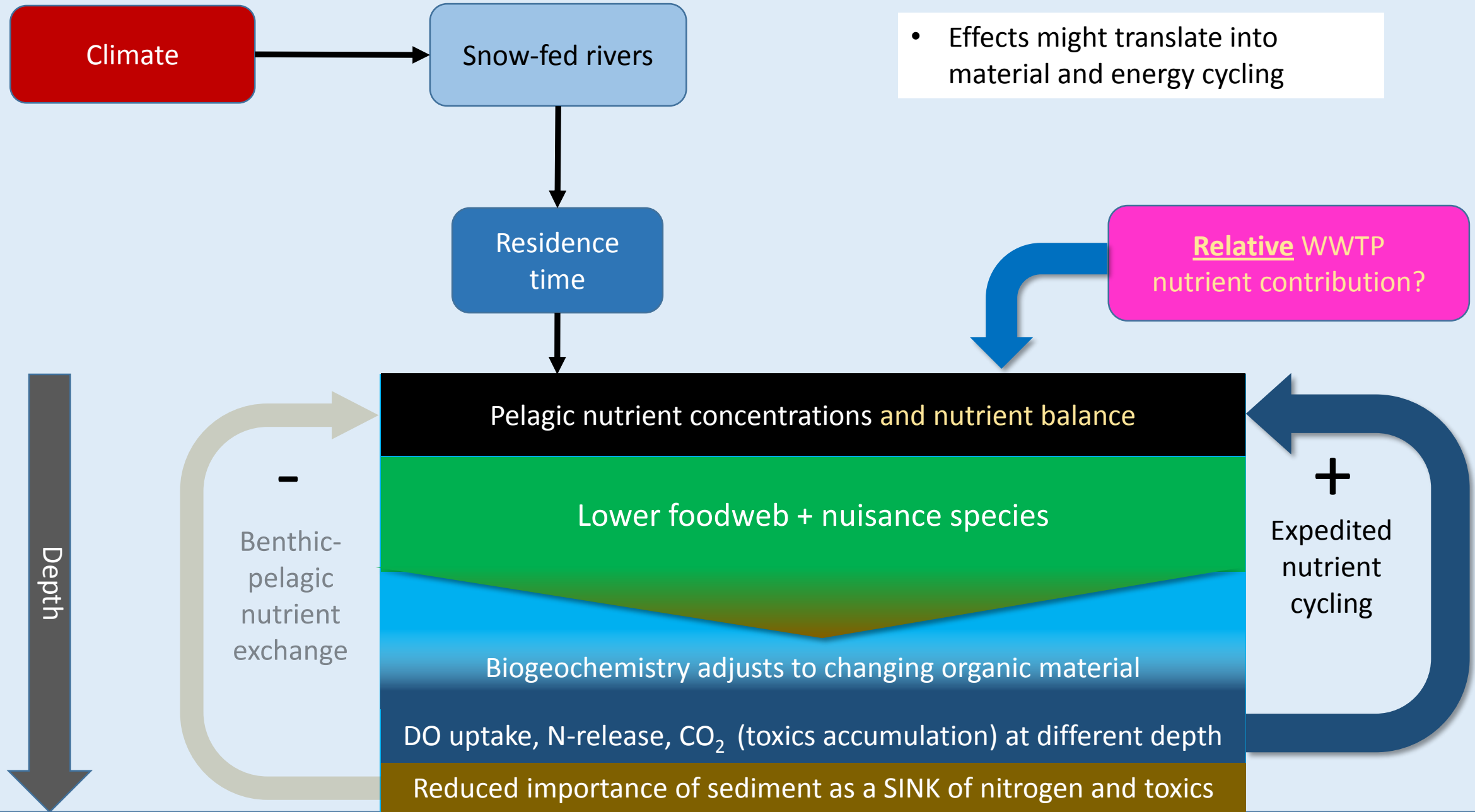


# SUMMER (June to Sept)





# SUMMER (June to Sept)



# Unexplained changes in the sediment. Food supply?

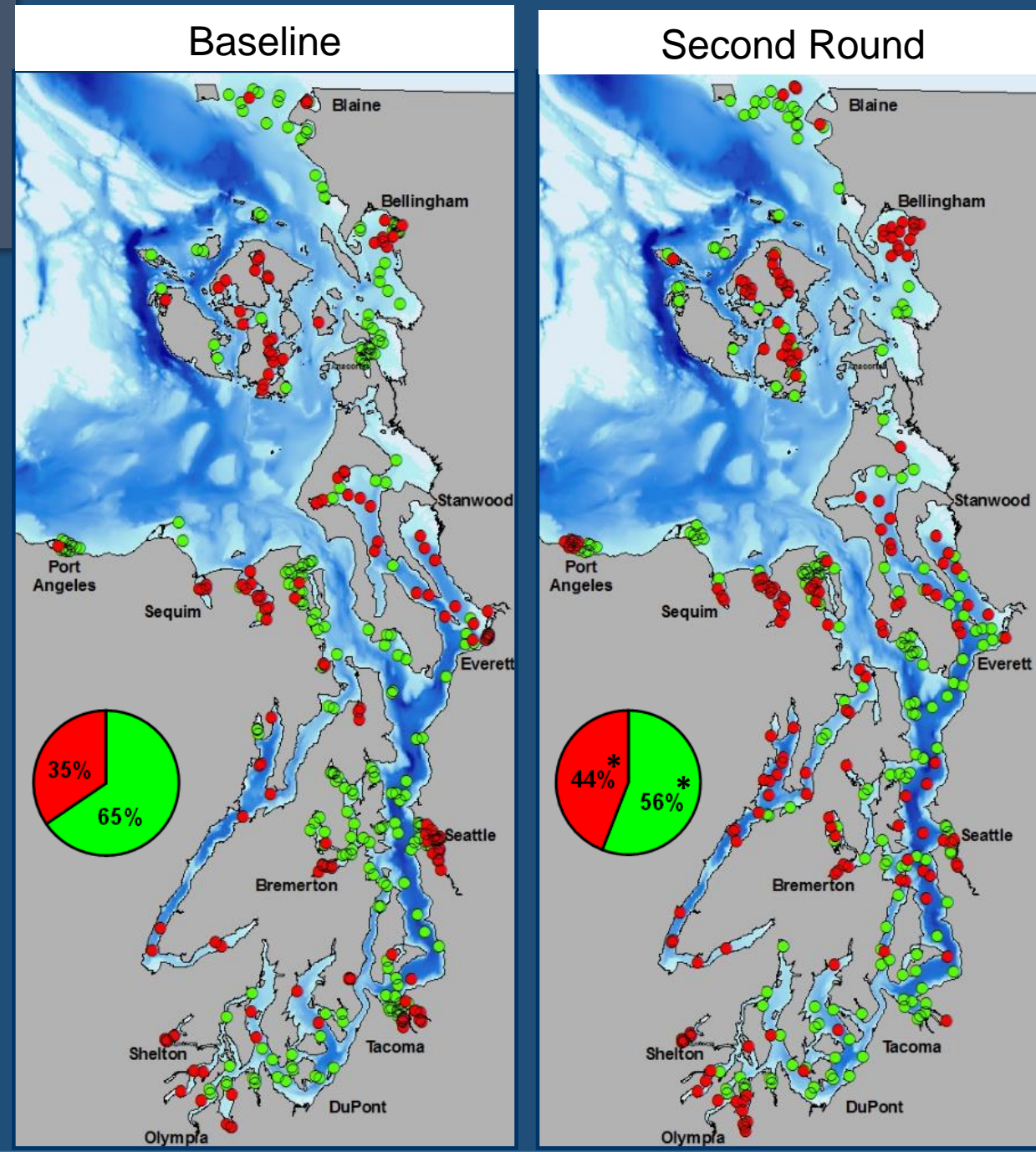
## Ecology's Benthic Index categories

● Unaffected ● Adversely affected

Increase in the areas with *adversely affected* benthos

- Decadal decline in benthic abundance and taxa richness
- Detritivores most affected

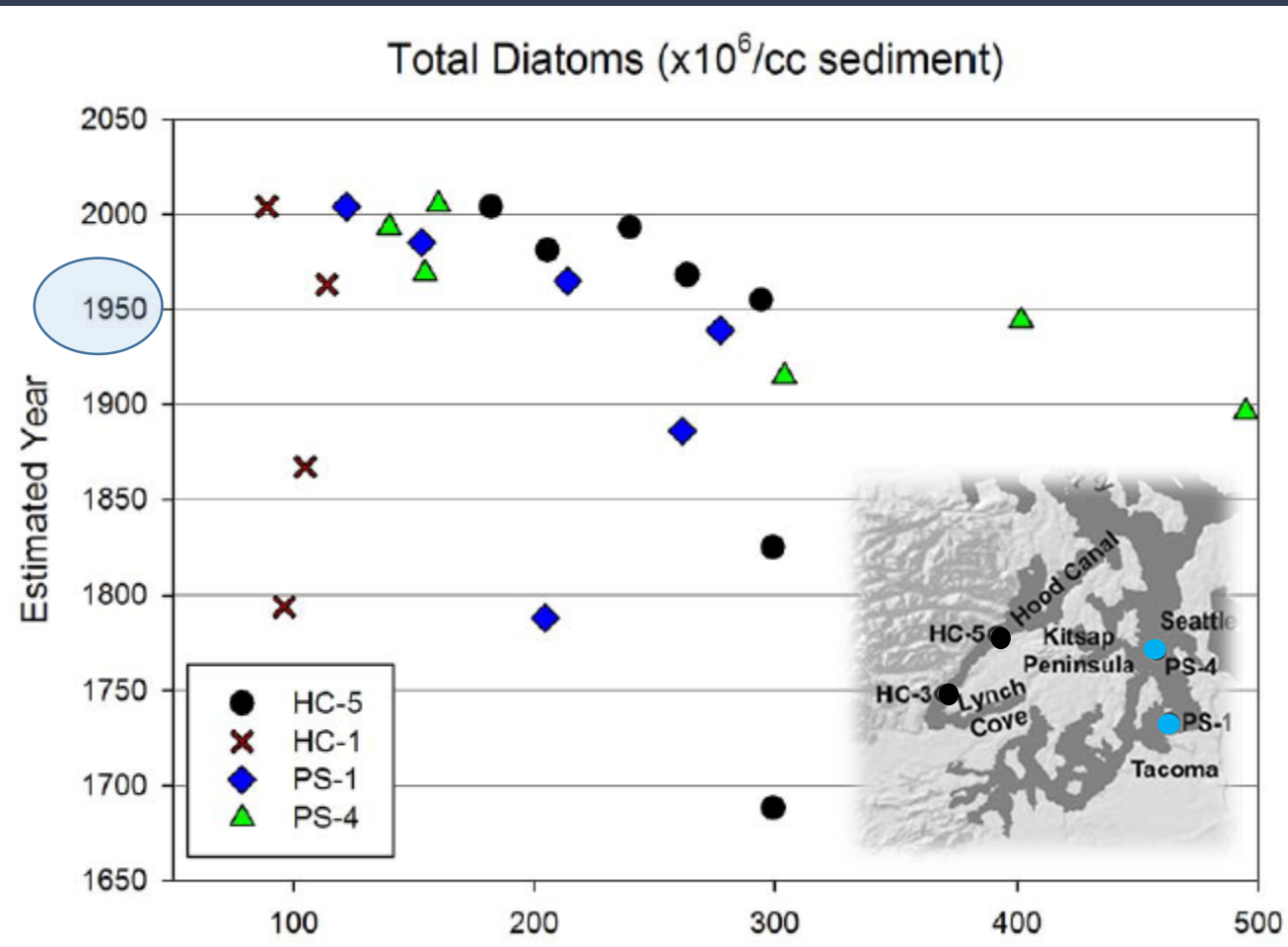
Are these potentially signs of a reduced food supply (particle export) to the benthos?





# Trends in the sediment record before 1999?

Brandenberger et al. 2008



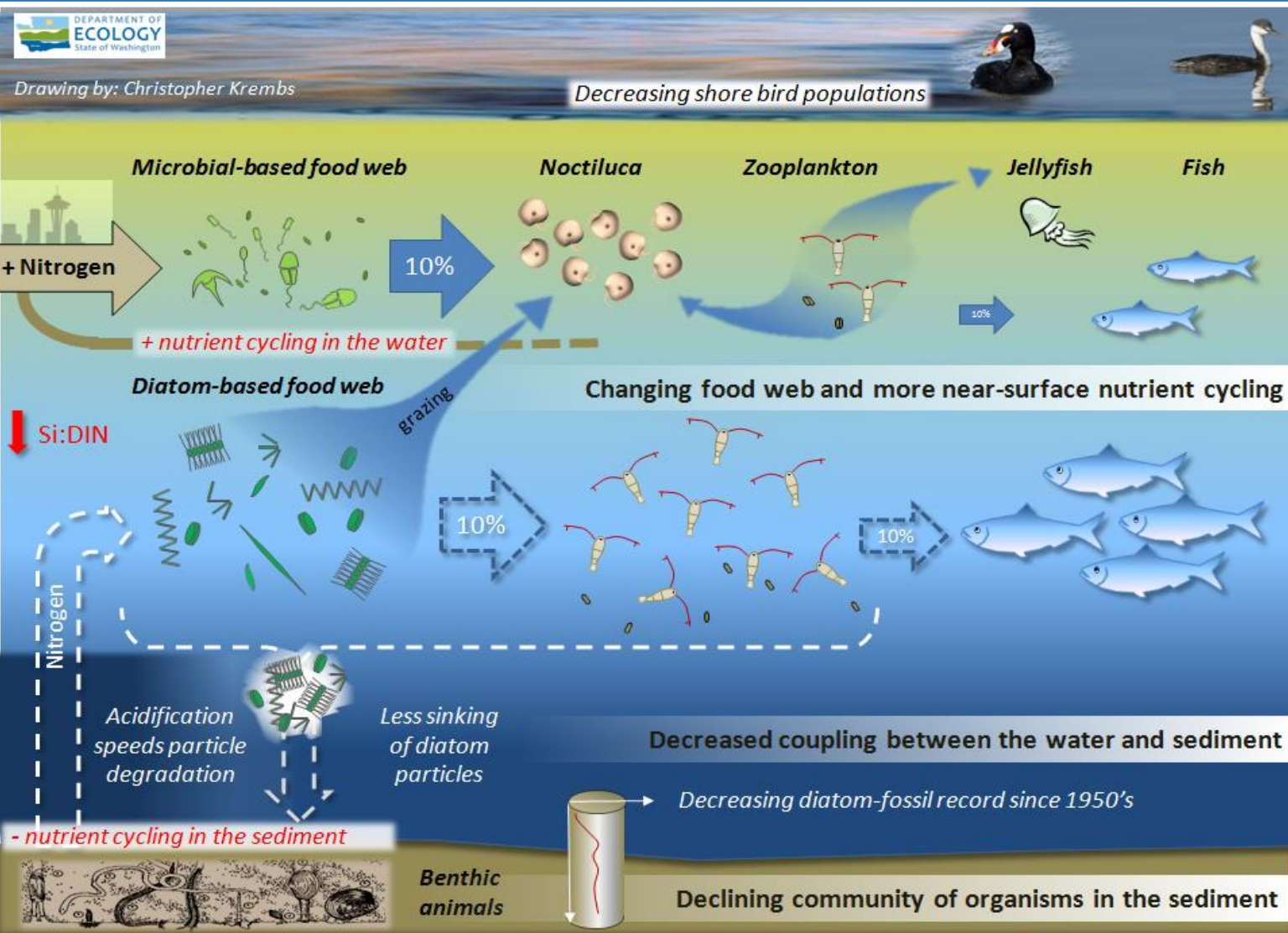
**Reconstructing Trends in Hypoxia Using Multiple Paleoecological Indicators Recorded in Sediment Cores from Puget Sound, WA.**

*NOAA Coastal Hypoxia Research Grant*

Diatoms have been declining since 1950 in Puget Sound

*Report, Figure 39.* Diatom valve abundance in each cubic centimeter of wet sediment (shown in millions of valves) for Puget Sound (PS-1 and PS-4) and Hood Canal (HC-1 and HC-5) sediment cores. The y-axis indicates estimated year of samples determined by  $^{210}\text{Pb}$  chronology.

# Hypothesis: Changes in the lower foodweb



The energy and material cycling through the lower and intermediate food web of Puget Sound are changing.

Natural oceanic variability and known nitrogen loads cannot explain the observed patterns.

The big unknowns are microbial foodweb, PP, grazing, and particle export (rates, dynamics, trends, composition)



# Important Topic

Vasas et al. 2007

HAB-forming species and *Noctiluca* **stimulate the microbial network**, but reduce higher trophic levels (fish).

The loss of planktivorous fishes acts together with nutrient enrichment in promoting **HAB species, *Noctiluca* and jellyfish.**

Vol. 336: 1–14, 2007

MARINE ECOLOGY PROGRESS SERIES  
Mar Ecol Prog Ser

Published April 27



## FEATURE ARTICLE

### Eutrophication and overfishing in temperate nearshore pelagic food webs: a network perspective

Vera Vasas<sup>1,4,\*</sup>, Christiane Lancelot<sup>1</sup>, Véronique Rousseau<sup>1</sup>, Ferenc Jordán<sup>2,3</sup>

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<sup>2</sup>Collegium Budapest, Institute for Advanced Study, Szentháromság u. 2, 1014 Budapest, Hungary

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<sup>4</sup>Present address: Department of Plant Taxonomy and Ecology, Eötvös Loránd University, Pázmány Péter s. 1/C, 1117 Budapest, Hungary

**ABSTRACT:** We investigated the effects of human activities on the pelagic food web structure of nearshore marine ecosystems. Their generic structure was established on the basis of literature review and analyzed by qualitative structural network analysis. Two main issues were addressed: (1) the role of species capable of forming harmful algal blooms (HABs) and red tides (*Noctiluca* spp.), as well as the role of jellyfish, in eutrophicated systems; (2) the contribution of human influences on food webs, focusing on bottom-up (increased nutrient loading) and top-down (overfishing) effects. Results suggest that HAB-forming species and *Noctiluca* stimulate the microbial network, but reduce higher trophic levels such as commercially important fish species. Jellyfish act as a buffer in eutrophicated and overfished systems, as they retain nutrients from the water column, but their blooms lead to a massive accumulation of large phytoplankton organisms. Anthropogenic nutrient enrichment favors undesirable species because of their specific position in the food web, and this crucial position may explain their far-reaching effects. Finally, while it appears that overfishing of piscivorous fishes inhibited HABs and supported blooms of diatoms and other large algae in the past, the present-day loss of planktivorous fishes acts synergistically with nutrient enrichment in promoting HAB species, *Noctiluca* and jellyfish. These fundamental constraints, which are inherent in the generic structure of pelagic food webs, thus largely determine community dynamics in marine coastal ecosystems.

**KEY WORDS:** Food web · Eutrophication · Overfishing · Network analysis · Coastal ecosystem · Indirect effects · Harmful algal blooms · Gelatinous plankton

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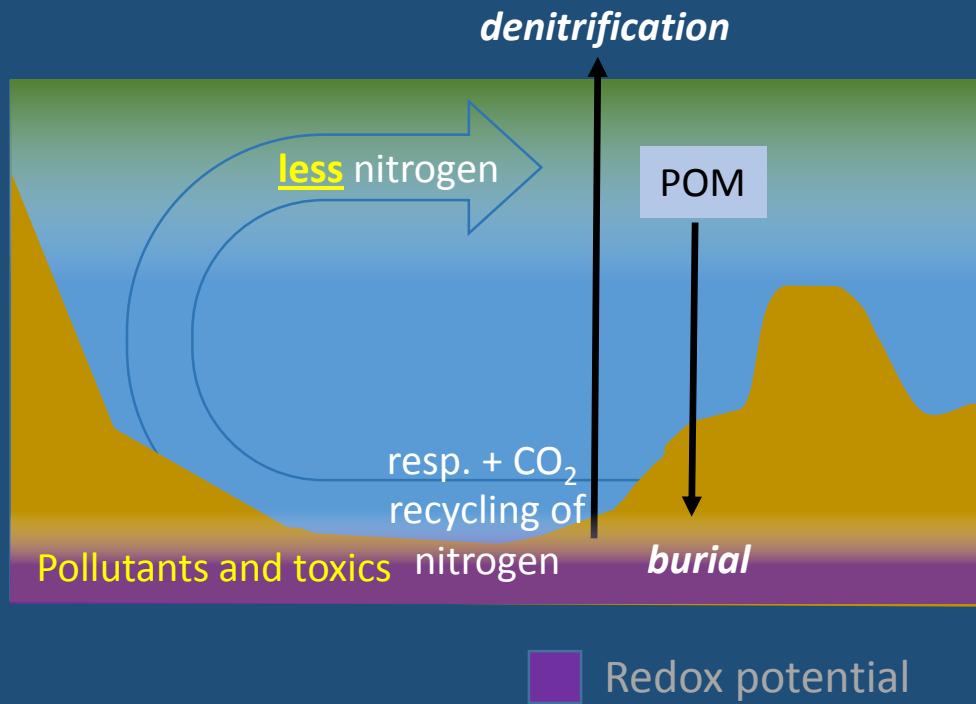
Eutrophication and overfishing are threatening marine coastal communities worldwide. Visible consequences are harmful algal blooms and jellyfish outbreaks. The analysis of the pelagic food web structure by Vasas et al. (diagrammatically idealized above) helps us to understand the mechanisms by which eutrophication and overfishing can generate ecosystem shifts.

Illustration: Sándor Snapp; background from Google Earth™

## INTRODUCTION

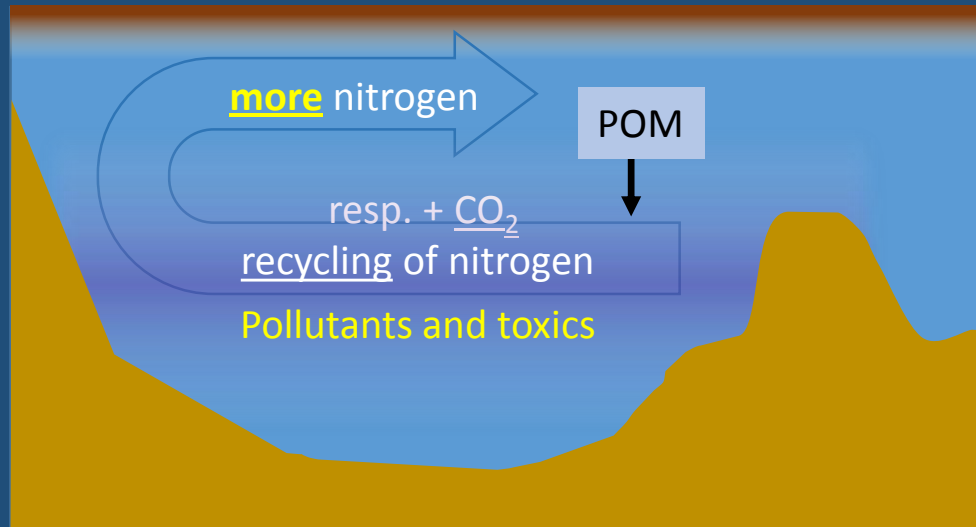
Coastal waters receive large amounts of anthropogenic nutrients from domestic and industrial effluents and agricultural runoff. Effects of coastal eutrophication are discernible at all trophic levels (Cloern 2001) and appear as direct and indirect qualitative changes in pelagic food webs, e.g. proliferation of harmful algal blooms (HABs), extinction of species at higher trophic levels, and reduced yields of harvestable fishes and invertebrates. These alterations of the food web struc-

\*Email: vvasas@yahoo.com



**Fast sinking:**  
Diatom based  
food web,  
recycling and  
burial at  
bottom

A different **particle flux**  
increases pelagic  
pollution/toxics and  
**diminishes loss terms** via  
the sediment



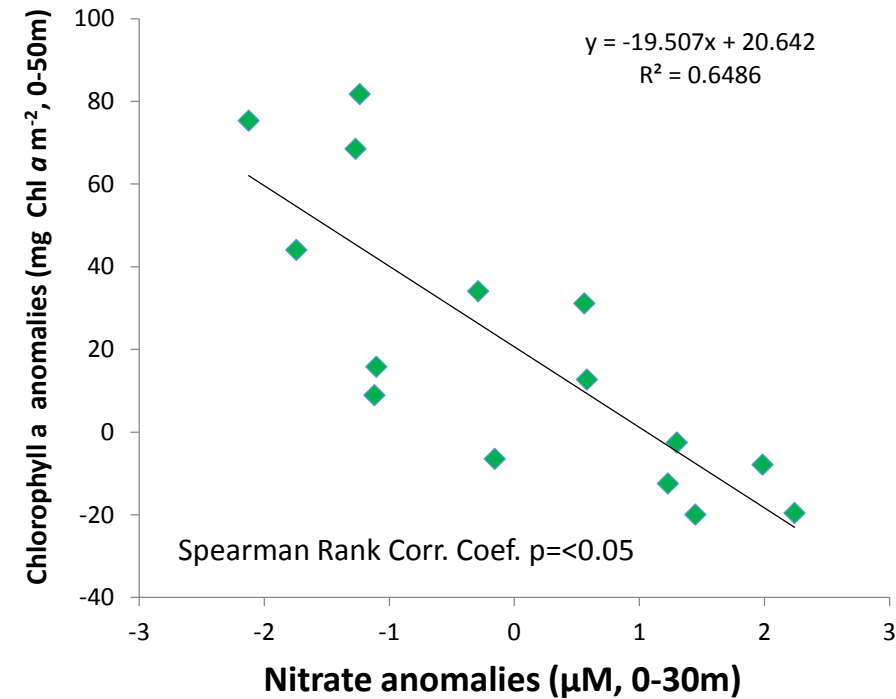
**Slow sinking:**  
Microbial based  
food web,  
recycling mid-  
water

Upward shift of phytoplankton and remineralization in the water column. This results in lowering of nitrogen losses (burial and denitrification)



# Inter-annual variability in phytoplankton biomass could explain changes in macro-nutrients?

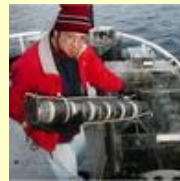
Nitrate and Chl  $a$



Micro-zooplankton (<200 μm)

**Micro-zooplankton grazers can remove **the entire** diatom standing stock each day!**

**Balance between microzooplankton grazing and phytoplankton growth in Dabob Bay (Hood Canal)...**



Leising et al., 2005. The balance between microzooplankton grazing and phytoplankton growth in a highly productive estuarine fjord. Progress in Oceanography 67:366–383.

Predator-prey  
balance

Shift could have  
significant effects  
that ripple through  
the foodweb

What controls phytoplankton inter-annual variability  
could also control nutrients in Puget Sound?

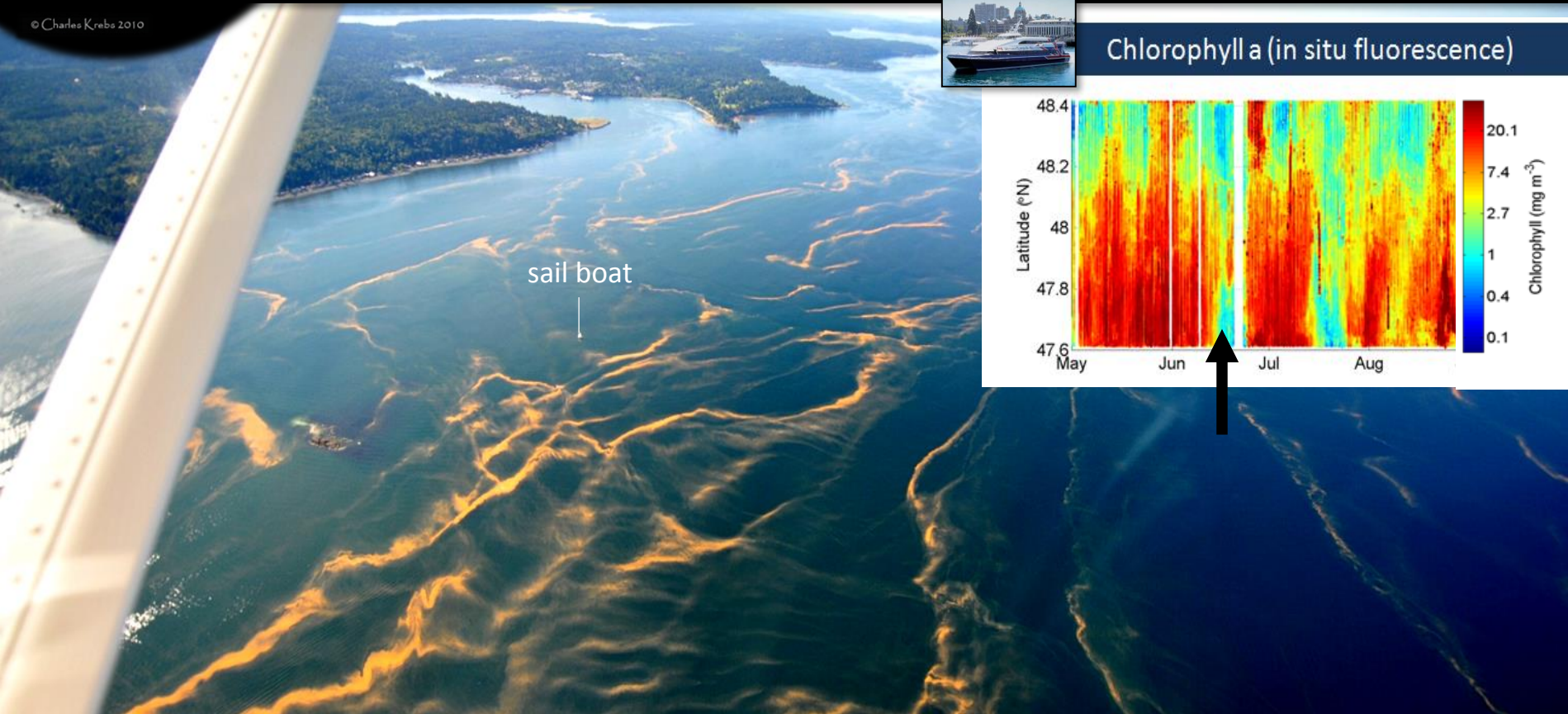
# *Noctiluca* blooms are large (eutrophication indicator)

**A strong competitor to copepods that feed on diatoms!**

**Food : No food preference!** (*Diatoms, flagellates, detritus, nauplii, copepod and fish eggs...*)



© Charles Krebs 2010



*Noctiluca* is occurring on a scale that is very visible to the naked eye

*Noctiluca* rapidly recycles sinking fecal pellets and retains nutrients in the surface.

(Kiørboe, Thomas 2003)



# Decadal Changes in Seabird Foraging Activity, Forage Fish, and Plankton in Cattle Pass, San Juan Islands

Emily S. Runnells

Master of Science

University of Washington, 2014

terenphotography.com

## In Conclusion



1990s > 2010s

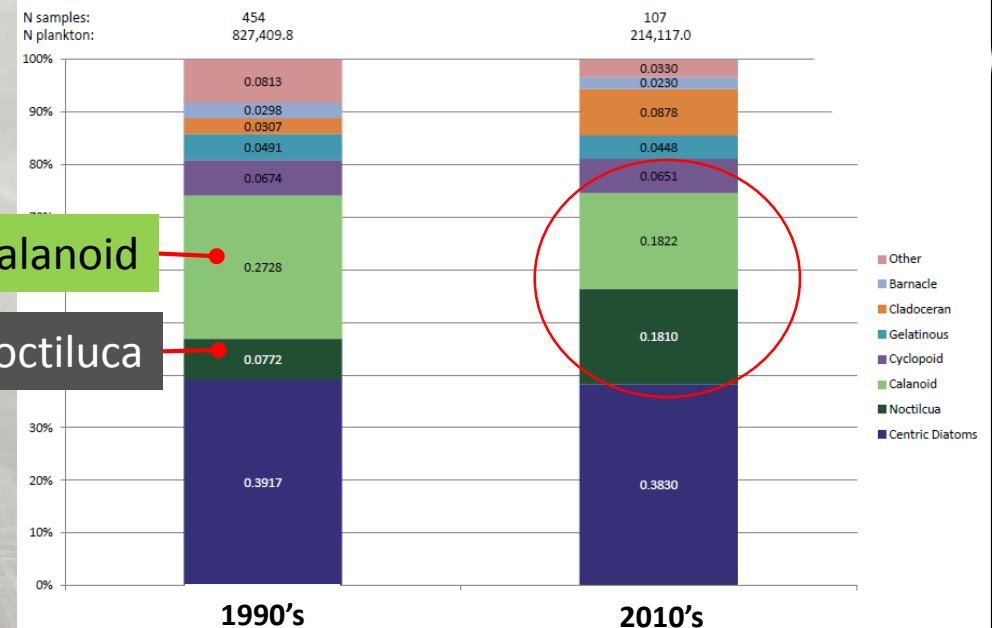


1990s > 2010s



1990s > 2010s for  
Calanoid Copepods  
Shift in community  
composition

## Plankton Community Composition



1) Change not limited to Puget Sound. 2) The effect potentially cascading to higher trophic levels.



Hypothesis:

Energy and  
material cycling  
in Puget Sound

A Team Approach



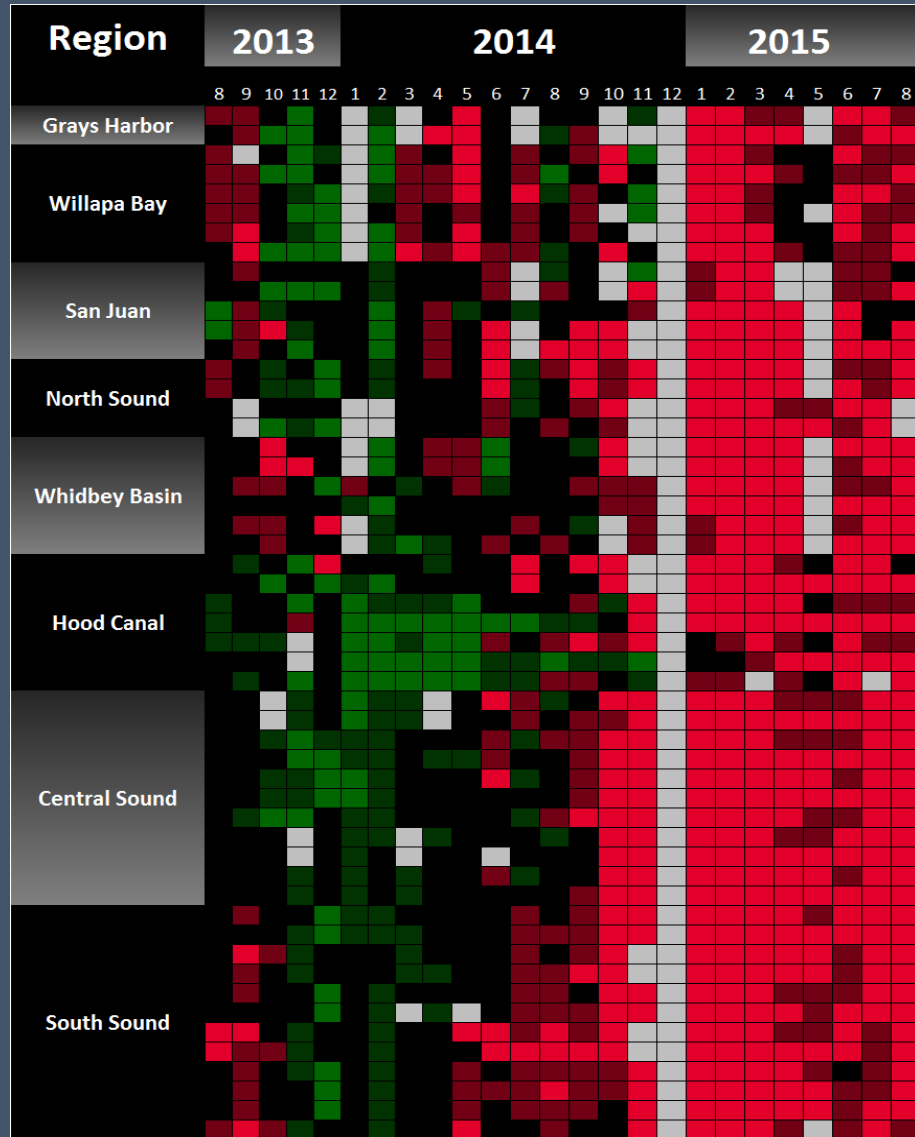


# R. flows, biogeochemistry and lower food web are relevant to the understanding of water quality trends in Puget Sound.

- HS: Changes in river summer flows affect the growth conditions of the lower levels of the marine food web.
- Water retention time in Puget Sound
  - Nutrient quality, nutrient balance, nutrient dilution (WWTP gain in relative importance)
- HS: In summer, the microbial network has gained importance relative to the linear productive diatom-based food chain.
- HS: The org particle export to deeper water changed qualitatively and quantitatively in response to shifts in the lower-trophic levels of the foodweb.
- HS: Mid-water biogeochemical processes increase while those of the sediment decrease (DO and toxics uptake, release of nutrient + CO<sub>2</sub> at intermediate depths).

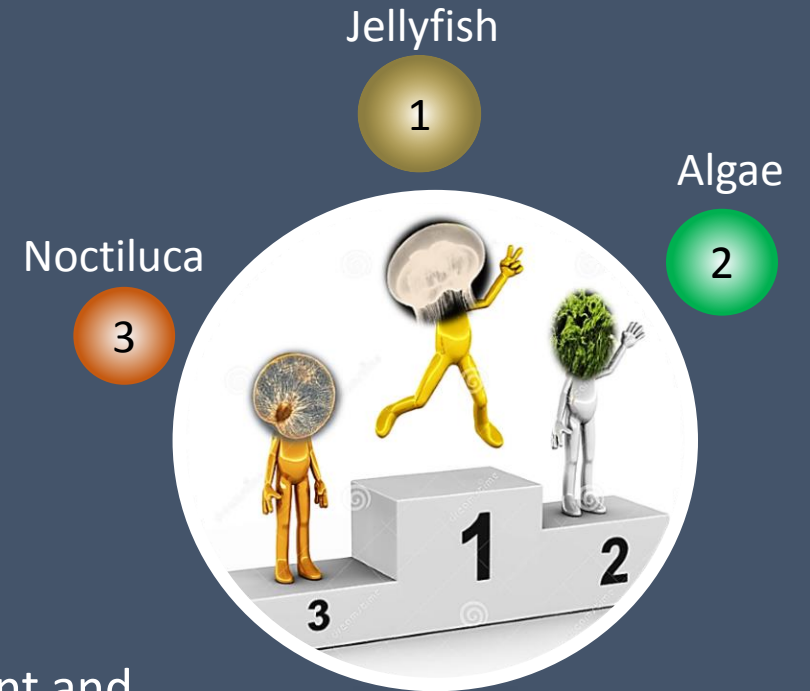
# Qualitative assessment of the effect of recent warm water on Puget Sound's food web.

Water temperature very high in 2015



## The “Blob” And the future?

- Jellyfish were very abundant and persisted through the year.
- Macro-algae patches were extensive.
- Noctiluca & dinoflagellate blooms were sizable, but comparable to recent years.
- Events overlapped.







*Picture by Mya Keyzers*

## Eyes Over Puget Sound:

We will continue to  
provide updates on  
developing conditions